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JAMES G. PARTLOW

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James G. Partlow

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by

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Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
PHYSICS

United States Naval Postgraduate School
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ABSTRACT

Acoustic methods have been used to detect and analyze periodic pressure fluctuations in a weakly ionized neon glow discharge. A pressure sensitive condenser microphone was used as a plasma probe. Comparison of acoustic pressures with the light intensity fluctuations measured with a photomultiplier tube have been made in an attempt to investigate a possible relationship between pressure fluctuations and moving striations.

Neutrally charged particles have been shown to be the mechanism of the pressure fluctuations. Identical frequency measurements of the pressure fluctuations and moving striations, and a correlation between their intensities, indicate a relationship between the two phenomena.

The writer wishes to express his gratitude to Dr. O. B. Wilson for his guidance and assistance throughout this project. Appreciation is also expressed to Dr. N. L. Oleson for his interest and counsel.

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1. Introduction

After one hundred years of observation and study, no definite theory has been established to adequately explain the origin and dynamics of the phenomenon of moving striations in a gaseous discharge. A search of scientific literature yields an abundance of experimental data and an occasional attempt to incorporate a theory which is in agreement with observation. To date, however, none of the theories explaining moving striations have withstood the constructive criticism of the many researchers in the field. Excellent summaries and comment on early and recent work in the field are covered extensively in papers by Thomson[1] and Cooper[2], and will not be covered here.

A relationship between moving striations and neutral molecule density waves, excited into oscillation by ionization waves, was first suggested by Watanabe and Oleson.[3]

The argument for neutral molecule density waves as a mechanism for moving striations has been complimented by Robertson and Hakeem,[4]

[1] J.J. Thomson, The Conduction of Electricity through Gases, Cambridge University Press, 1933, 3rd Ed., Vol. 2.

[2] A.W. Cooper, Moving Striations in the Inert Gases, Ph.D. Thesis, Queens University of Belfast, 1961.

[3] M.S. Watanabe and N.L. Oleson, Traveling Density Waves in Positive Columns, Phys. Rev. 99, 1701, (1955)

[4] H.S. Robertson and M.A. Hakeem, Proceedings of the Fifth International Conference on Ionization Phenomena in Gases, North Holland Pub. Co., (1962) pg. 550.

who demonstrated the dependence of moving striations upon neutrally charged metastable atoms in the positive column of a glow discharge.

The concept of moving striations as a density wave of neutrally charged metastables is the basis for a current theory of the dynamics of striation phenomena. It has been established by earlier work that striations originate from within the plasma itself and that their occurrence is not directly dependent upon conditions at the boundaries or electrodes of a plasma column. Although not yet clearly established, the current theory is compatible with these findings by equating the excitation energy of striation density waves to the energy available within a plasma as a result of transitions between the metastable and the ground states of the ionized gas.

Investigation of neutral molecules as the dynamic mechanism of moving striations has been a continuing project at the U. S. Naval Postgraduate School. This study of the acoustic properties of a plasma column was initiated as an experiment in the investigation of the current striation theory because of the inherent ability of acoustic techniques in verifying or discounting the presence of a density or "sound" wave in any type of medium.

2. Experimental Procedure

Moving striations are most readily observed in the plasmas of weakly ionized noble gases. Investigation of striation phenomena has centered on the positive column of these plasmas while operating under glow or corona discharge conditions. Electrostatic probe and optical photomulitplier techniques have become traditional diagnostic tools in the investigation of moving striations.

The general procedure of this study has been to establish the above described plasma in neon gas and to incorporate a pressure sensitive microphone as a third, and principal, tool for observation of the striations. The microphone's sensitivity to pressure and density fluctuations within the plasma provide a means of investigating the existence of a density wave, while the use of a photomultiplier allows for the comparison of acoustic signals with the characteristic fluctuations of light intensity of the moving striations. Synchronization of light and pressure signals (if existent) by a dual beam oscilloscope triggering technique would then provide the frequency, phase, and velocity information necessary in establishing some relationship between moving striations and density waves in the plasma.

3. Experimental Equipment

3.1 Discharge Tube

The discharge tube was fabricated from pyrex tubing of 4.5 cm. inside diameter and 79 cm. length. The tantalum disc electrodes were supported and centered in the discharge tube as shown in figure 1. Iron cores, sealed in glass, and attached to the electrodes, allowed the electrodes to be moved individually along the tube by the magnetic force induced by applying a small voltage to the movable copper coils wound around the outside of the discharge tube. With this arrangement, the length of the plasma column could be adjusted up to a maximum length of 25 cm.

As shown in figure 1, the discharge tube was fitted with appendages for housing a microphone and a Langmuir probe. The probe was also constructed with a metal core to allow rádial positioning in the plasma column.

Since the microphone and Langmuir probe could not be moved along the tube, movable electrodes were necessary in order to allow the two sensors to examine the entire length of the plasma column. This could be accomplished by moving each of the electrodes an equal amount, thus maintaining the length of the column, while effectively moving the microphone and probe to new positions in the plasma.

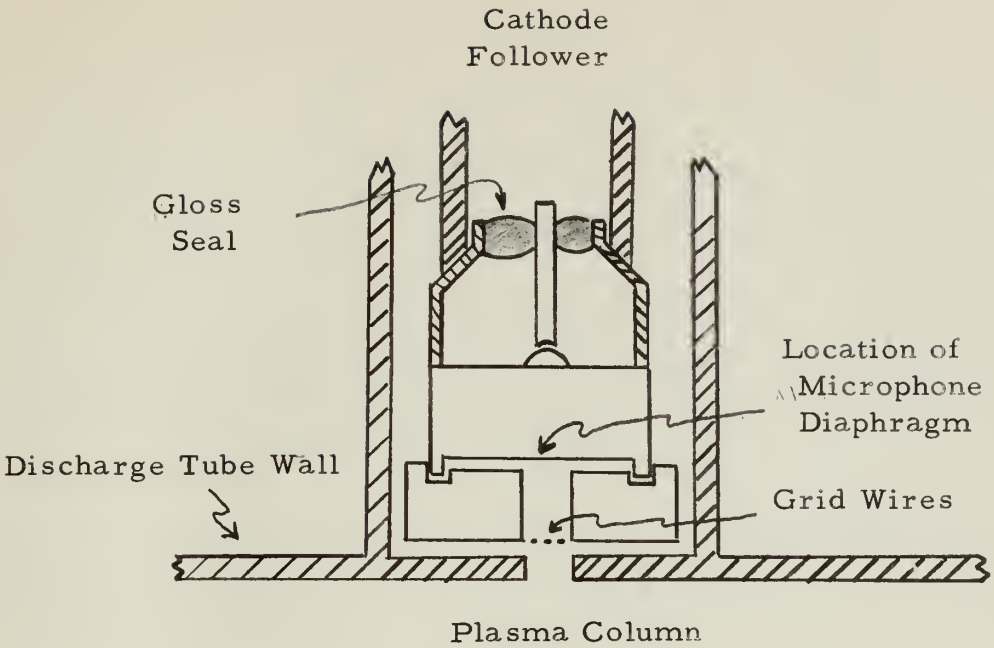


Fig 1A Microphone Detail (Schematic)

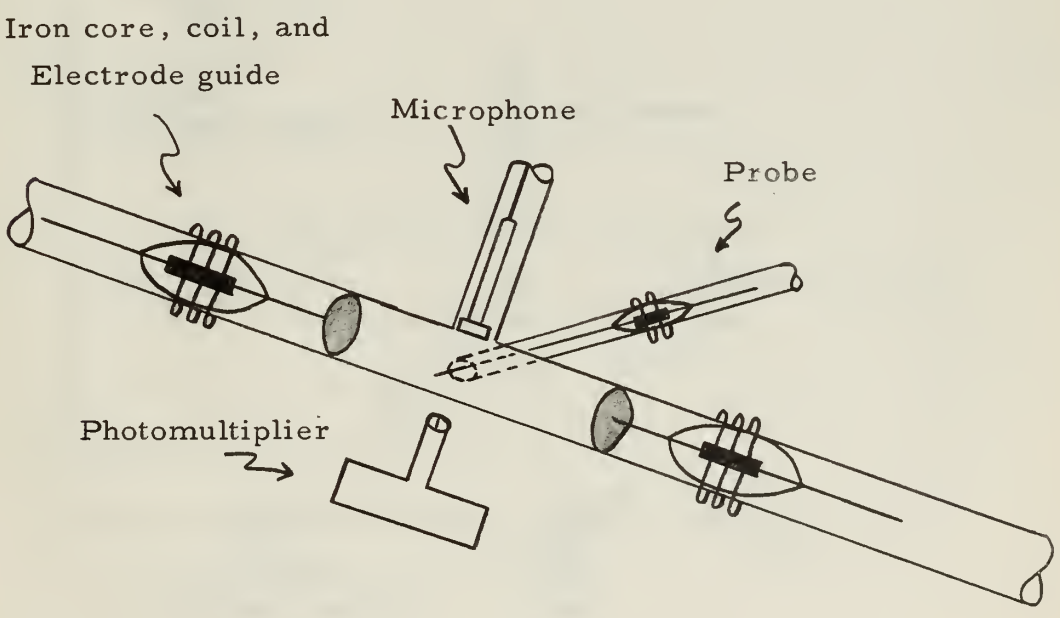


Fig 1B Discharge Tube and Probes (Schematic)

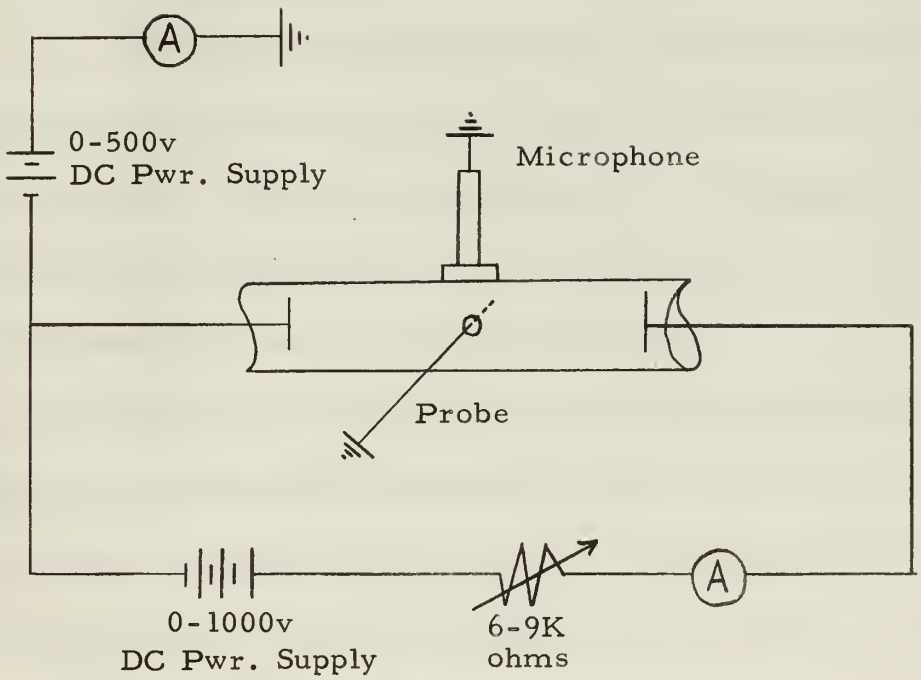


Fig 2. Electrical Discharge Circuit

3.2 Discharge Circuit

The DC glow discharge was established using the circuit shown in Fig. 2. A Kepco DC voltage-regulated power supply and appropriate series resistance allowed operation in the glow discharge range, characterized by discharge currents in the milliampere range. The Kepco power supply provided 0-1000 DC voltages, regulated to within .1 volt with less than 3 millivolt ripple. The microphone and electrostatic probe were maintained at ground potential. The 0-500 volt DC power supply, a Hewlett-Packard model 712A, was used to vary the potential of the grounded microphone relative to the discharge by shifting the potential of the main power supply relative to ground potential.

3.3 Vacuum System

The glass discharge tube was evacuated by direct "O" ring connection to a metal vacuum system, constructed by USNPGS shop personnel. This system consisted of a 3/4 horsepower Kinney mechanical fore pump with a 5 cu. ft./min. capacity, a 750 watt oil diffusion pump, and a liquid-air filled trap.

Pressures in the vacuum system were monitored by a thermocouple gauge in the diffusion pump fore line, and by thermocouple and ionization gauges on the low pressure side of the diffusion pump, near the glass-to-metal "O" ring seal. At this position, pressures of the order of 10^{-8} mm. Hg. were readily attained.

3.4 Acoustic Equipment

Density fluctuations in the discharge were measured by means of an Altec 21BR 150-3 condenser microphone, mounted as shown in Fig. 1. The microphone was coupled into the main discharge tube through a small, short aperture in the side wall. The Altec 526B microphone power supply was modified to supply 100v polarizing voltage instead of the usual 200v. This modification was necessary in order to reduce the heat and associated "noise" occurring in the cathode follower amplifier because of the close confines of the glass housing. One end of the glass housing for the cathode follower contained glass-sealed conductors for connection to the microphone, which was located in the vacuum system.

The output signal voltage of the cathode follower was then analyzed by passage through a Bruel and Kjoer one-third octave band filter and displayed on a Hewlett-Packard Type 551A dual beam oscilloscope.

In the measurement of acoustic signals in a gaseous discharge, one encounters the problem of detecting a very weak signal in an electrically noisy environment. The presence of charged particles in the plasma and the electrical radiation from many sources in the vicinity of the laboratory contribute to an electrical noise level that is prohibitively high in proportion to the acoustic signals being measured. Copper shielding of all power and microphone signal leads reduced the level of electrical noise to a degree that, using

the maximum sensitivity of all read-out instruments, the acoustic signal from the microphone could be detected above the remaining noise level.

In order to protect the microphone diaphragm from damage by ion bombardment, a fine conducting mesh was placed over the small hole in the microphone casing leading to the diaphragm.

The RMS magnitudes of the plasma pressure fluctuations were determined using the microphone frequency response characteristic which is given in Appendix 1. The magnitude of the RMS over-pressures detected under various discharge conditions are summarized in Table 1.

4. The Plasma Column

Gas was admitted to the discharge tube from a one liter Linde high purity neon gas bottle through a stopcock and metering bulb arrangement. Gas pressures were measured with an Octoil-S oil manometer to within .5 mm. Hg.

The plasma column was then established by ionization of the neon. The degree of ionization was estimated to be of the order of .1%. With the discharge equipment employed, it was possible to vary the current of the discharge up to a maximum of 60 ma., at which point arcing between the electrodes, microphone, and probe became evident. When first established, the plasma column was characterized by instabilities resulting from anode spotting. After a few minutes, however, a stable plasma column could be maintained by small adjustments in the discharge current.

Throughout the study, attempts to maintain a pure neon plasma were unsuccessful. With fresh gas in the discharge tube, the plasma was initially characterized by the familiar neon red color, followed by a gradual change to a pink and then blue color. Attempts to remove the impurities from the system included several cleansings of the discharge tube with acid cleaning solution, the use of heating tapes, and repeated cycles in which the discharge was run at high currents, followed by evacuation of the tube with the discharge potential still established.

It appears that in order to rid the system of impurities, the pyrex glass tubing must be raised to a much higher temperature than is available using heating tapes. The presence of the microphone and several ground glass surfaces, held together with vacuum grease, precluded the use of torches to bake out the system while maintaining a vacuum.

The fact that the plasma under study was not pure neon does not necessarily detract from the validity of the experiment. At very low gas pressures (less than .5 mm. Hg.), the discharge could be made to regain its red neon characteristic, indicating that, in spite of the presence of an impurity, the discharge retained some of the characteristics of a neon plasma.

5. Observations and Discussion

Pressure fluctuations in the plasma column were detected over a wide range of discharge conditions. Representative frequencies and amplitudes are shown in Table 1. When detected, the acoustic signals were always accompanied by the presence of moving striations, as evidenced by the characteristic fluctuations in light intensity signal from the photomultiplier tube. Pressure fluctuations in the plasma were never observed in the absence of moving striations. There were many instances in which no acoustic signal was detected, even though striations were present. It is assumed that, in these instances, the magnitude of the pressure fluctuations was below the threshold sensitivity of the microphone for that particular frequency. A conclusion that pressure fluctuations are always present whenever there are moving striations in the plasma, may not be valid.

For every simultaneous observation of the photomultiplier and microphone signals, the frequency of the moving striations and of the pressure fluctuation signals was found to be the same. Fig. 3 shows representative light intensity and acoustic signals as observed on the synchronized dual beam oscilloscope. Analysis of the acoustic signals by the filter also indicated that the pressure wave form usually contained harmonics of the fundamental component. Harmonics could most readily be observed when their frequencies

P (mm. Hg.)	I (ma)	Striation and Acoustic Freq. (cps)	RMS Pressure Amplitude ($Dynes/cm^2$)
1.5	20	4000	6.0×10^{-4}
2	7.5	5700	1.5×10^{-5}
3	4	830	3.8×10^{-4}
3	9	3700	5.6×10^{-4}
3.5	6	2100	4.0×10^{-3}
3.5	10	2100	8.0×10^{-3}
4	4	2900	1.3×10^{-3}
4	14	3100	1.1×10^{-3}

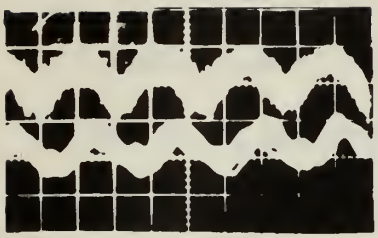
Table I

were near the microphone resonance. As before, an assumption that the presence of a fundamental and harmonics is a characteristic of all frequencies is not necessarily valid.

The two wave forms were also found to have a strong correlation in amplitude characteristics in that large variations in light intensity were accompanied by relatively large periodic pressure fluctuations.

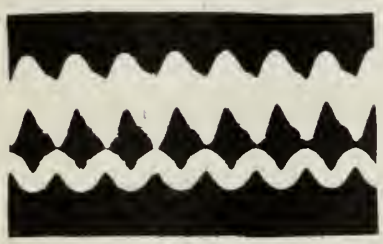
In the representative wave oscillograms shown in Fig. 3, the positive peaks of the traces represent minimums in light intensity and rarefactions in pressure. It was observed that for any given discharge condition (current, gas pressure, etc.) the phase relationship between these two signals remains constant. Upon changing the discharge conditions, however, a different constant phase relation is established. Although the frequency of the two signals was identical for all discharge conditions, there appears to be no definite phase relationship between the periodic fluctuations in pressure and light intensity.

Attempts to determine whether the periodic pressure fluctuations represent a standing acoustic wave or a propagating acoustic wave have been unsuccessful. The microphone position relative to the plasma column was changed by simultaneous movement of the electrodes an equal distance inside the discharge tube. If a propagating wave is present, a change in phase should be evident in



Striation and Acoustic Freq. = 2.1 KC

Striation and Acoustic Freq. = 3.1 KC



Striation and Acoustic Freq. = 3.7 KC

Upper trace represents Photomultiplier signal. Lower trace represents Microphone signal

Fig. 3 Microphone and Photomultiplier Oscillograms

the acoustic signal as the microphone is moved longitudinally in the column. Such a phase change would not be present in the case of a standing wave. This method of analyzing the microphone signal proved to be unsuccessful because of changes in the discharge conditions resulting even after the most careful moving of the electrodes. Throughout the study, it was most often found that the slightest change in any of the discharge parameters would greatly change the appearance of the probe, photomultiplier, and microphone signals. In this particular experiment, the magnetic field used to move the electrodes caused a significant change in the discharge characteristics, thus making it impossible to detect the presence or absence of a phase change in the acoustic signal at a new position in the plasma. The discharge tube and its appendages make up a somewhat complex acoustic system. Movement of the large electrodes in the tube has a considerable effect upon its acoustic characteristics, thus hampering an analysis of the wave form as the electrodes are moved.

The fact that pressure fluctuations were not always detected when moving striations were present in the plasma has been attributed to limited microphone sensitivity at frequencies other than those for which the microphone response is resonant. The detection of only certain acoustic frequencies could also be attributed to the presence of a standing wave in the column. In this case, acoustic pressures would be detected only when the microphone was located near a

pressure anti-node for the various normal modes of oscillation which are governed by the dimensions of the tube. An investigation of the normal modes of the discharge tube filled with air at atmospheric pressure was made by placing a small sound source near the anode end of the tube and observing the normal modes by measuring the response of the probe microphone. The relative positions of the electrodes and microphone were the same as those usually used when operating the discharge. Normal modes were observed over a wide range of frequencies. It was noted that one particularly strong mode was present at 2.5 KC, a frequency at which acoustic signals were often detected in the plasma.

As previously described, the discharge circuit was arranged such that the electric potential of the microphone relative to the discharge potential near the microphone could be varied. Thus, when driven to either a positive or negative relative potential, the microphone was made to repel either the ions or the electrons present in the discharge. Upon detection of an acoustic signal in the plasma, the relative potential of the microphone was changed while observing the form of the acoustic signal on the oscilloscope. The wave form was not observed to change during these variations. Thus it is concluded that oscillations of charged particles at the microphone do not contribute significantly to the pressure fluctuations. The result is perhaps not too surprising since a weakly ionized plasma is made up

mostly of neutral particles. The result is significant, however, when considered in the light of the present theory that neutral molecules serve as the dynamic mechanism of moving striations. If there exists a direct relationship between striations and neutral metastables, then the demonstrated direct relationship between neutral particle oscillations and the observed acoustic pressure fluctuations also supports the argument that the moving striations are in some way related to the pressure fluctuations.

6. Conclusions

Acoustic techniques are believed to be an effective addition to the methods of plasma diagnostics. The results of this study are insufficient to make any definite conclusions about the details of the relationship between moving striations and the presence of neutral particle pressure waves in a plasma. However, the detection of pressure waves accompanied by striations, and their demonstrated identical frequency characteristics and amplitude correlation indicate that the theory is promising. Further acoustic probing into the type of pressure waves present and their phase relative to the moving striations are recommended as rewarding areas of work in the study of striation phenomena.

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APPENDIX

MICROPHONE CALIBRATION

The pressure response characteristics of condenser microphones at low pressures are significantly different from those at atmospheric pressure. The Altec 21-BR microphone was calibrated at a pressure of 10 mm. Hg. by comparing its response to a Western Electric condenser microphone type 640 AA whose low pressure response characteristics are known.[5] The calibrated microphone was placed in the discharge tube near the probe microphone and a small sound source was positioned near one end of the tube. The system was evacuated to 10 mm. Hg. and the response of each microphone was noted as the frequency of the sound source was varied. The response of the microphone probe relative to the calibrated microphone was then applied to the response characteristics of the calibrated microphone to obtain the calibration curve of Fig. 4.

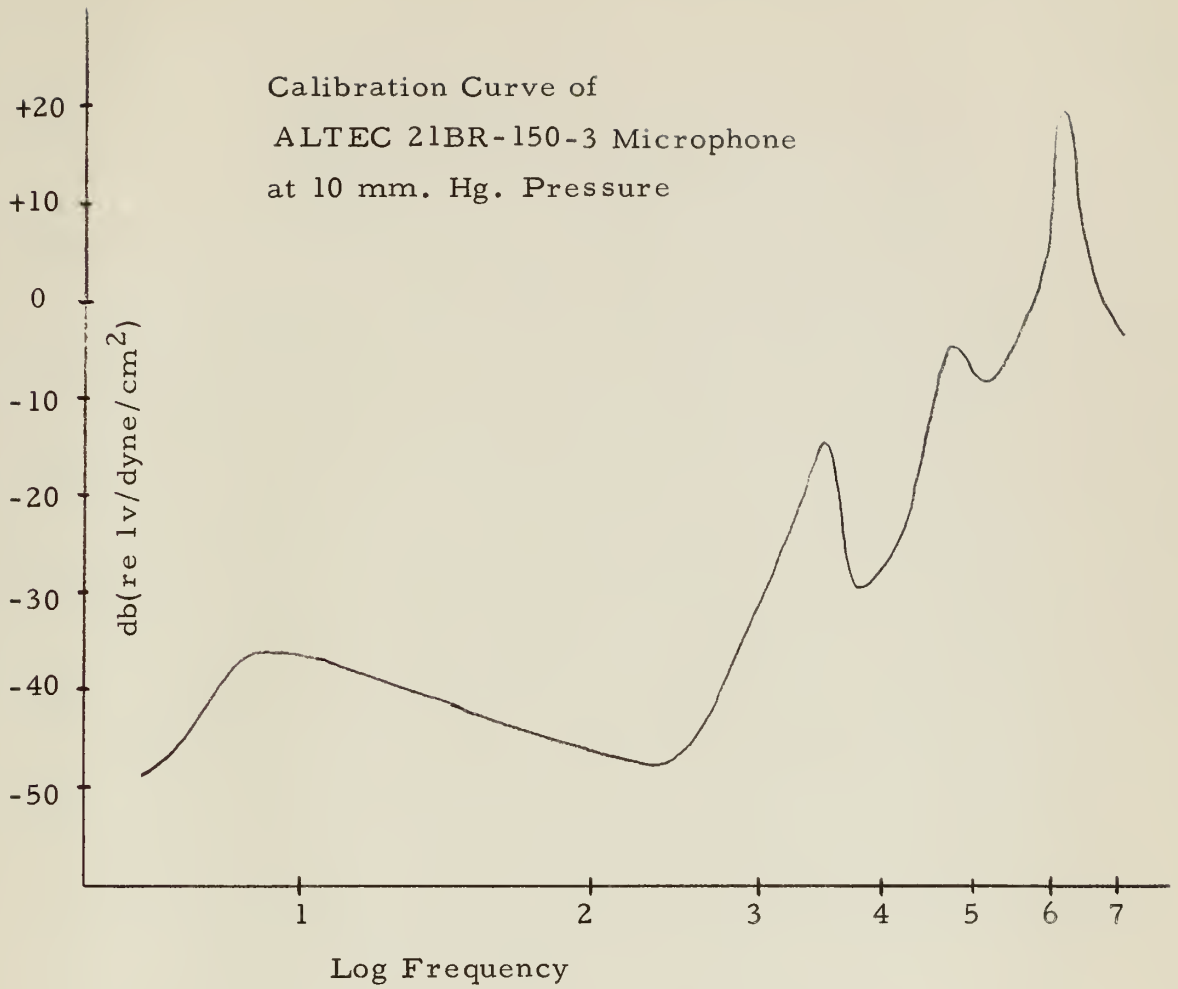

Fig 4. Microphone Calibration Curve

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Measurement of acoustic pressures associ
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